

Freshwater Quality Monitoring Protocol
San Francisco Area Network

Standard Operating Procedure (SOP) # 9

FIELD METHODS FOR FLOW MEASUREMENTS

Version 1.01

August 2005

REVISION HISTORY LOG:

| Prev. Version # | Revision Date | Author | Changes Made | Reason for Change | New Version # |
|--------------------|------------------|--------------------|---------------|---|------------------|
| 1.0 | 8/3/05 | Mary Coopridner | Minor changes | Finalizing for formal peer review | 1.01 |
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Only changes in this SOP will be logged. “Version numbers increase incrementally by hundredths (e.g. version 1.01, version 1.02, ...etc) for minor changes. Major revisions should be designated with the next whole number (e.g., version 2.0, 3.0, 4.0 ...). Record the previous version number, date of revision, author of the revision, identify paragraphs and pages where changes are made, and the reason for making the changes along with the new version number” (Peitz et al, 2002).

Suggested Citation: Coopridner, MA. 2005. Field Methods for Flow Measurements, Version 1.01, Standard Operating Procedure #9. *In* San Francisco Bay Area Network Freshwater Quality Monitoring Protocol, Version 2.1, Appendix H-SOPs, National Park Service, San Francisco Bay Area Network, CA. 51 pp. plus appendices.

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ACKNOWLEDGEMENTS

Significant portions of this SOP were taken directly from the Greater Yellowstone Network's (GRYN) SOP #5 – *Procedures for Collection of Required Field Parameters* (O'Ney, 2005). We appreciate the time and effort devoted to this and other SOPs written by Susan O'Ney.

1.0 INTRODUCTION

The San Francisco Bay Area Network (SFAN) Water Quality Status Report provides an overview of flow monitoring locations and history within the SFAN parks (Cooprider, 2004). Stream gauges are located in watersheds within Golden Gate National Recreation Area (GOGA), John Muir National Historic Site (JOMU), and Point Reyes National Seashore (PORE). These stream gauges are equipped with a pressure transducer water level monitor and automatically record stage height at 10-15 minute intervals. These stream gauges have been managed by the individual parks. However, SFAN staff are currently considering methods of consolidating the maintenance and operation of these stations into the SFAN Freshwater Dynamics program. Staff implementing the Freshwater Dynamics program will focus on creating hydrographs (rating curves), operating the stream gauges, and managing the data. Stream flow measurements will be taken at cross sections near these gauges in order to obtain a stream flow rating curve that provides a relationship between stream stage and stream discharge. Once a rating curve is established for a stream gauge then water level can be used to predict stream flow. In addition to automated stream gauges, there are also several staff gauges located throughout the parks. Some of the SFAN long-term water quality monitoring stations are co-located with stream gauges and/or staff gauges.

Flow measurements collected in conjunction with water sample collection and stream chemistry measurements are critical to the SFAN Water Quality Monitoring Program. First, flow measurements are necessary to determine where to collect field measurements and samples. Flow measurements also provide useful information about seasonal variability in water quality parameters and pollutant load estimates. Therefore, quantitative streamflow will be assessed at all water quality monitoring sites where practical. Where time or stream conditions do not permit flow measurements then a qualitative estimate will be provided. Other methods and instructions on when to use a particular method will be discussed further in the SOP.

2.0 CALIBRATION

2.1 Calibration of Current Velocity Meters (Flow meters)

(from O’Ney, 2005)

All technicians should review “Measurement of Stream Discharge by Wading” by Michael Nolan and Ronald R. Shields, USGS Water Resources Investigations Report 00-4036, available on CD. Also, refer to USG Technical Memorandum, found at <http://water.usgs.gov/admin/memo/SW/sw99.06.html> for the care of vertical axis current meters.

Field teams may be using one of three types of current velocity meters, a photooptical impeller type meter (e.g., Swoffer Model 2100) a vertical axis meter (e.g., Price type AA), or an electromagnetic type meter (e.g., Marsh McBirney Model 201D). General guidelines regarding performance checks and inspection of current meters are presented below. Consult the operating manual for the specific meter and modify this information as necessary.

2.2 General Performance Checks

(From Peck et al., 2001)

2.2.1 Photoelectric Impeller Meters (e.g., Swoffer Model 2100)

- Check that the calibration adjustment cover screws are tightly fitted on the display case.
- Periodically check the condition of the connector fitting between the display unit and the sensor.
- Connect the sensor to the display unit and check the calibration value stored in memory. If this value is less than the correct value for the display unit-sensor rotor combination, replace the batteries.
- Periodically perform a spin test of the rotor assembly, following the instructions in the meter’s operating manual. A displayed count value of 300 or greater is indicative of satisfactory performance at low current velocities.
- If a buzzing sound occurs when the rotor assembly is spun by hand, or if the shaft shows visible wear, replace the rotor assembly.
- Periodically examine the thrust-bearing nut on the rotor assembly. If a “cup” begins to form on the bottom surface of the nut, it should be replaced.

2.2.2 Vertical-axis Meters (from Smoot and Novak, 1968)

- Inspect the bucket and wheel hub assembly, yoke, cups, tailpiece, and the pivot point each day before use.
- Inspect the bearings and check the contact chamber for proper adjustment.
- Periodically conduct a spin test of the meter. The minimum spin time is 1.5 minutes, while the recommended time is between 3 and 4 minutes.

2.2.3 Electromagnetic Meters

- Check the meter calibration daily as part of morning routine. Calibration value should be 2.00 ± 0.05 .
- Once per week, check the zero value using a bucket of quiescent water. Place the probe in the bucket and allow to sit for 30 minutes with no disturbance. The velocity value obtained should be 0.0 ± 0.1 . Adjust the meter zero if the value is outside this range.
- An annual calibration by the manufacturer or by the USGS Hydrologic Instrumentation Facility (Stennis Space Center, Mississippi) is recommended.

3.0 MEASUREMENT TECHNIQUES

Stream discharge will be measured quantitatively by using the USGS method for measurement of stream discharge (Rantz et al., 1992). The flow velocity (ft/s) will be taken using the Marsh-McBirney Flo-Mate, Swoffer 2000 flow meter, or pygmy meter. A top-setting wading rod (measured in tenths of feet) and a tape measure with gradations every tenth of a foot are also required equipment. A cross-section of the stream is chosen and the stream is divided into panels or sections. The width, depth, and velocity of each section is then recorded. Discharge is the sum of measurements in each panel and is recorded in cubic feet per second (ft³/s).

Field personnel are encouraged to review the USGS tutorial CD *Measurement of Stream Discharge by Wading* (Nolan and Shields, 2000). It provides details on the process and theory of stream flow measurements and proper methods and equipment. It is also important to have a hydrologist or someone well-versed in discharge measurement techniques to assist with training of field personnel. Consult the SFAN Freshwater Dynamics Monitoring Protocol (in development) for more background and details on flow monitoring. Coordinate with the Freshwater Dynamics program personnel when possible.

Stream discharge measurements can be obtained from the following:

- USGS gauging station
- National Park Service stream gauge with established rating curve
- Mechanical flow meter (e.g., Pygmy current meter, AA, Swoffer 2000)
- Electric flow meters (e.g., Marsh-McBirney Flo-Mate)
- Orange peel or trained eye estimate
- Qualitative descriptions

3.1 Quantitative Methods

(from O'Ney, 2005; Adapted from Texas Commission on Environmental Quality, 2003)

3.1.1 Introduction

Flow/discharge measurements representative of field conditions are needed to determine where to collect field measurements and samples. When flow is measured first, take care not to deploy a multiprobe instrument or to collect water samples in the area disturbed during flow measurement. The method (or instrument) used to measure flow must be reported.

When flow cannot be measured:

The following are two exceptions to the requirement for obtaining flow measurements:

- **No flow and pools.** If there is no flow at a stream site, and accessible, isolated pools remain in the stream bed, collect and report the required field data and

laboratory samples from the pools and report instantaneous flow. Under these conditions, report flow (ft³/s) as zero.

- **Dry.** If the stream bed holds no water, no sampling is required. Report that the stream was "dry" in the observations.

3.1.2 Measuring Flow

Several methods exist for measuring discharge but most methods share several similar steps. They include:

1. Selection and calibration of a current meter or other means of determining velocity
2. Proper site selection
3. Dividing the channel cross-section into equal increments (usually 25 or more)
4. Making the current measurements (by meter or other means) at several points in the vertical while allowing enough time for the device to stabilize (40 seconds for most current meters)
5. Determining the mean velocity at each vertical
6. Tabulating the data in field notes
7. Making field computations using the tabulated data

Equipment used to measure discharge or flow (e.g. current meters) should be tested/calibrated prior to mobilization to the field. Consult the manufacturers manual for specific calibration methods and appropriate applications for selected current meter and other devices used in the flow/discharge determinations.

3.1.2.1 Recording flow data

Record the following information on a flow measurement form (see Appendix A) for a blank form):

- Station location and station ID
- Date
- Time the measurement is initiated and ended
- Name of person(s) measuring flow
- Total stream width and width of each measurement section
- The midpoint, section depth, and flow velocity for each cross section
- Staff gage reading

Do not round values when recording flow data. For example, if the velocity is 1.99 do not round to 2.0. If each value is rounded on the worksheet, it could introduce an error in the final value. Only the final value is rounded.

3.1.2.2 Establishing a cross section profile

Stretch the measuring tape across the stream at right angles to the direction of flow. When using an electronic flow meter, the tape does not have to be exactly perpendicular to the bank (direction of flow). When using a propeller or pygmy

type meter, however, make corrections for deviation from perpendicular. Measure and record the stream width between the points where the tape is stretched (waters edge to waters edge).

If necessary, the measuring cross section can be modified on smaller, low-flow streams. This can be done by building dikes to cut off dead water and shallow flows, remove rocks, weeds, and debris in the reach of stream 1 to 2 meters upstream from the measurement cross section. After modifying a streambed, allow the flow to stabilize before starting the flow measurement.

3.1.2.3 Determining the number of flow cross sections

Determine the spacing and location of flow measurement cross sections. Some judgment is required, depending on the shape of the stream bed. Measurements must represent the velocity within the cross section. Fewer measurements are needed if the stream banks are straight, the depth nearly constant, the bottom is free of large obstructions, and the flow is homogeneous over a large section. Flow measurement sections should be of equal width, unless an obstacle or other obstruction prevents an accurate velocity measurement at that point. *No single cross section should have greater than 10 percent of the total flow.* The rule of thumb is as follows:

- If the stream width is less than 5 feet, cross sections widths are 0.5 feet.
- If the stream width is greater than 5 feet but less than 10 feet, the minimum number of cross sections is 10.
- If the stream width is greater than 10 feet, the preferred number of cross sections is 20 to 30.

3.1.2.4 Determining the midpoint of the cross section

To find the midpoint of a cross section, divide the cross section width in half, as described below.

- The total stream width is 26 feet with 20 cross sections, and the width of each cross section is equal to 1.3 feet ($26/20 = 1.3$).
- Divide 1.3 feet in half to get the midpoint of the cross section, 0.65 feet. In this example the measuring tape at waters edge is set at 0.0 feet.
- Add 0.65 to 0.0 to get the midpoint of the first section, 0.65 feet.
- Find each subsequent midpoint by adding the section width (1.3 feet) to the previous midpoint.
- Use the measuring tape to place the top-setting wading rod at 0.65 feet (from the bank) for the first measurement.
- Using a top setting wading rod, measure the depth at the midpoint of the first cross section and record to the nearest 0.01 feet. Total depth at each cross section is measured with the *depth gauge rod*. The depth is entered into Column C of the flow measurement form. Each single mark represents 0.10

feet, each double mark represents 0.50 feet, and each triple mark represents feet. See Figure 1, Top-Setting Wading Rod.

3.1.2.5 Adjusting the sensor depth at a cross section

Adjust the position of the sensor to the correct depth at each midpoint. The purpose of the top setting wading rod is to allow the user to easily set the sensor at 20, 60, and 80 percent of the total depth. See Figure 1, Top-Setting Wading Rod.

- If the depth is 1.5 feet or less, only one measurement is required at each cross section. To set the sensor at 60 percent of the depth, line up the foot scale on the *sliding rod* with the *tenth scale*, located on top of the depth gauge rod. If, for example, the total depth is 1.1 feet, then line up the **1** on the foot scale with the **1** on the tenth scale (Marsh McBirney 1990).
- If the depth is greater than 1.5 feet, two measurements are taken at 20 and 80 percent of the total depth.
 - **20 percent of the depth.** Multiply the total depth by 2. If the total depth is 3.1 feet, the rod would be set at 6.2 feet (3.1×2). Line up the **6** on the sliding rod with the **2** on the tenth scale.
 - **80 percent of the depth.** To set the sensor at 80 percent of the depth, divide the total depth by two. For example, the total depth is 3.1 feet and the rod would be set at 1.05 feet ($3.1/2$). Line up the **1** on the sliding rod between the **0** and **1** on the tenth scale. Use the average of the two velocity measurements in the flow calculation. See Columns D and E on the flow measurement form. When the depth is greater than 2.5 feet, never set the wading rod at the actual depth. In this case, it would not be set at 3.1 feet.

Note: The point where the rod is set for 20 and 80 percent of the depth will not equal values derived by calculating 20 and 80 percent of the total depth.

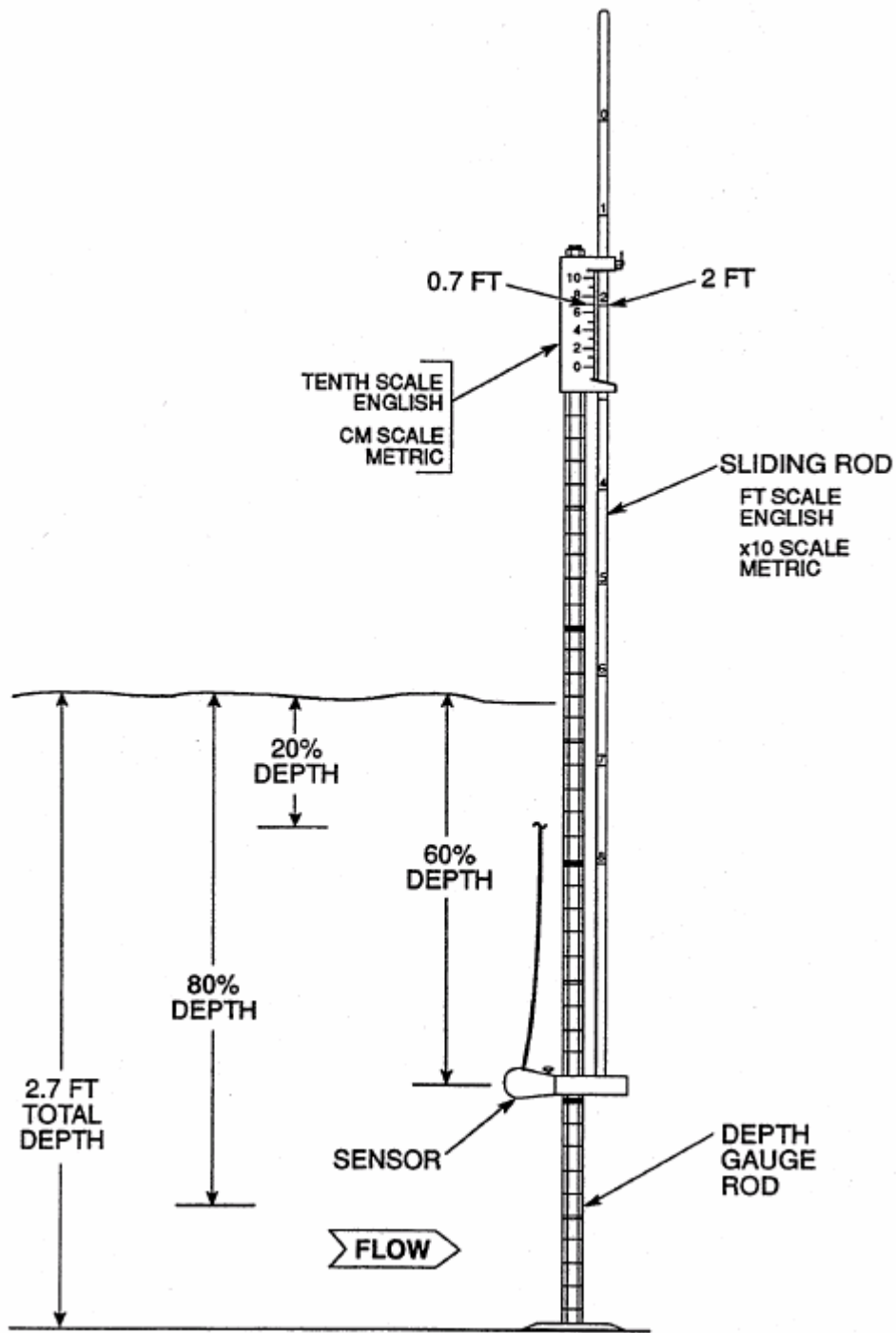


Figure 1. Top setting wading rod

3.1.2.6 Measuring velocity

Follow these steps to measure velocity:

1. Position the meter at the correct depth and place at the midpoint of the flow measurement section. Measure and record the velocity and depth. While measuring velocity with an electronic flow meter, keep the wading rod vertical and the flow sensor kept perpendicular to the tape, rather than perpendicular to the flow. When using a propeller or pygmy-type meter, however, the instrument should be perpendicular to the flow.
2. Permit the meter to adjust to the current for a few seconds. Measure the velocity for a minimum of 40 seconds (preferably 2 minutes with the Price and pygmy meters).
3. When measuring the flow by wading, stand in the position that least affects the velocity of the water passing the current meter. The person wading stands a minimum of 1.5 feet downstream and off to the side of the flow sensor.
4. In cases where the flow is low and falling over an obstruction, it may be possible to measure the flow by timing how long it takes to fill a bucket of known volume.
5. Avoid measuring flow in areas with back eddies. The first choice would be to select a site with no back-eddy development. However, this cannot be avoided in certain situations. Measure the negative flows in the areas with back eddies. These negative values will be included in the final flow calculation.

3.1.3 Calculating Flow

Follow these steps when calculating flow: Calculate flow at each cross section by multiplying the width (W) x depth (D) x velocity (V) to determine flow in cubic feet per second (cfs or ft³/sec). See Figure 3-4, Stream Flow (Discharge) Measurement.

Q = Total Flow (or discharge), W = Width, D = Depth, V = Velocity.

$$Q = (W_1 \times D_1 \times V_1) + (W_2 \times D_2 \times V_2) + \dots (W_n \times D_n \times V_n)$$

- When flow is calculated for each cross section add them together for the total stream flow (refer to Figure 2).
- For each individual cross section flow, **do not** round values. For example, if the calculated flow for a cross section is 1.23956, do not round. If each value is rounded on the worksheet, it could introduce an error in the final value.
- **Do not** treat cross sections with negative flow values as zero. Negative values obtained from areas with back eddies should be subtracted during the summation of the flow for a site.

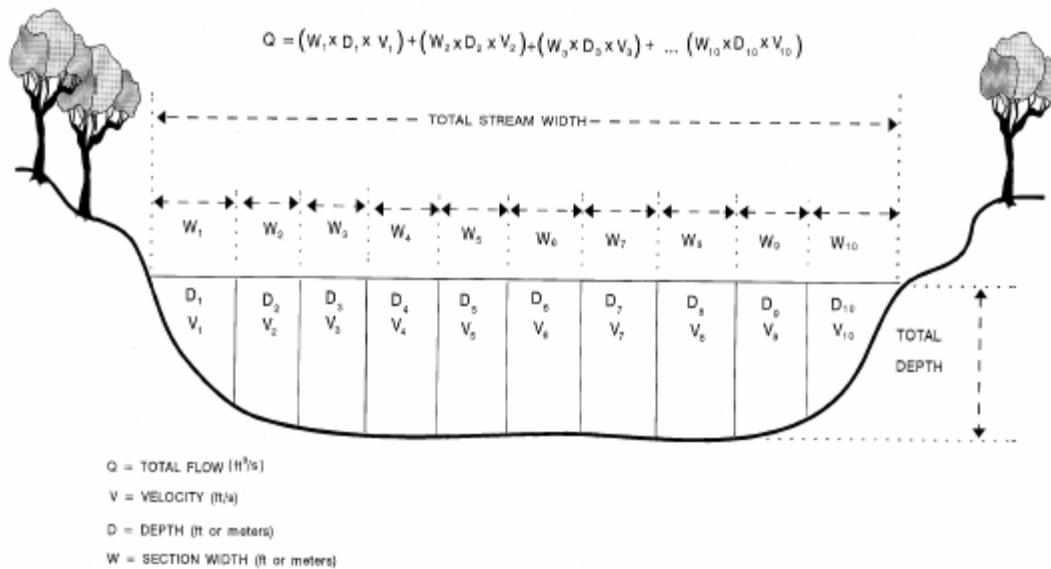


Figure 2. Flow calculations

3.1.4 Reporting Final Flow Values

Report instantaneous flow as follows:

- Report values **less than 10 but greater than 0.1 cfs** to the nearest tenth (for example, 9.35 to 9.4).
- Report values **greater than 10 cfs** to the nearest whole number (for example, 20.62 to 21).
- Report actual values **less than 0.1 cfs but greater than or equal to 0.01 cfs**. These values should not be rounded (for example, 0.07 would be reported as 0.07).
- Report **flow values < 0.01 cfs** as < 0.01. See Table 3-11, Final Format for Reporting Field Data.

When reporting final flow values, it is also useful to include the number of days since the last significant precipitation. Significant precipitation is defined as any amount that visibly influences water quality. Water quality in small to medium streams and in the headwaters of many reservoirs is influenced by runoff during and immediately after rainfall events. This influence is site specific and poorly studied. To understand and regulate the adverse effects of runoff, the SFAN would like to associate recent rains with ambient water quality, using a parameter defined as days since last significant precipitation.

Using best professional judgment, record the number of days, rounded to the nearest whole number, since a rainfall event that may have influenced water quality. Here are some guidelines:

- If it is raining when the sample is collected, or has rained within the last 24-hours, report a value of <1.
- If it has been a long time since a significant rain, record this as greater than that particular value, for example >7 days.

If confidence about the recent history of precipitation is low, don't report a value.

3.2 Alternative Methods

A qualitative flow measurement cannot always be obtained using the USGS established method. Equipment limitations and safety considerations may preclude taking flow measurements. Since flow measurements can be very important in determining pollutant loads or explaining measured parameters it is often useful to obtain an estimate. This usually occurs during storm events when stream flow is too high to safely obtain a traditional flow measurement. However, storm flows are often needed in order to understand pollutant loads. One method that can be used to estimate flow is the "orange peel" method. Citizen (volunteer) monitoring groups often employ this method as a safe, cost effective technique.

1. Establish a longitudinal stream length to measure and stretch the measuring tape across that length (from Point A to Point B). The length will depend on the velocity of the stream but 1-3 meters usually works well.
2. Using a stopwatch, record how long it takes the orange peel to float from Point A to Point B.
3. Throw the orange peel into the center of the stream or the thalweg if known. If available, have another person start and stop the stopwatch at your command.
4. It is recommended that you do this three times and take the mean of your three estimates. Alternatively, have other field crew members conduct the estimates.

As you become more familiar with each stream and obtain more and more flow measurements, you may find over time that you can estimate flow simply through visual observation. This can provide more information than a strictly qualitative estimate such as flow severity. Always indicate on the data sheet and in the database that your flow/discharge value was estimated.

3.3 Qualitative Methods

Flow severity, a qualitative estimation of flow is commonly used in water quality monitoring and is included as a field in NPSTORET. It is also used by the San Francisco Bay Regional Water Quality Control Board's Surface Water Ambient Monitoring Program (SWAMP). The SWAMP program monitors several sites within the SFAN parks.

Flow severity should be recorded for each visit to a freshwater streams. It should be recorded regardless of whether it was possible to measure flow. There are no numerical

flow guidelines associated with flow severity. This is an observational measurement that is highly dependent on the stream and knowledge of monitoring personnel. It is a simple but useful piece of information when assessing water quality data. For example, a bacteria value of 10,000 with a flow severity of 1 would represent something entirely different than the same value with a flow severity of 5. See Table 5 for detailed descriptions of flow severity values. The six flow severity values are; 1=No Flow, 2= Low Flow, 3 = Normal Flow, 4 = Flood, 5 = High Flow, and 6 = Dry. The following table includes descriptions of severity values.

Table 1. Flow Severity Values

| | |
|----------------|--|
| 1 | No Flow When a flow severity of one (1 = no flow) is recorded for a sampling visit, then a flow value of zero ft ³ /s should also be recorded for that sampling visit. A flow severity of one (1) (no flow) describes situations where the stream has water visible in isolated pools. There should be no obvious shallow subsurface flow in sand or gravel beds between isolated pools. Low flow does not only apply to streams with pools. It also applies to long reaches of bayous and streams that have no detectable flow but may have water from bank to bank. |
| 2 | Low Flow When stream flow is considered low a flow severity value of two (2) is recorded for the visit and the corresponding flow measurement is also recorded for that visit. In streams too shallow for a flow measurement but water movement is detected, record a value of < 0.10 cfs. Note: Use a stick or other light object to verify the direction of water movement, i.e., movement is downstream and not the effect of wind. What is low for one stream could be high for another. |
| 3 | Normal Flow When stream flow is considered normal, a flow severity value of three (3) is recorded for the visit and the corresponding flow measurement is also recorded for that visit. Normal is highly dependent on the stream. Like low flow, what is normal for one could be high or low for another stream. |
| 4 and 5 | Flood and High Flow Flow severity values for high and flood flows have long been established by USEPA and are not sequential. Flood flow is reported as a flow severity of four (4) and high flows are reported as a flow severity of five (5). High flows would be characterized by flows that leave the normal stream channel but stay within the stream banks. Flood flows are those which leave the confines of the normal stream channel and move out on to the flood plain. |
| 6 | Dry When the stream is dry a flow severity value of six (6 = dry) is recorded for the sampling visit. In this case the flow is not reported. This will indicate that the stream is completely dry with no visible pools. |

4.0 DATA ANALYSIS & REPORTING

The National Park Service Water Resources Division uses a database that is a modification of EPA's STORET database. This database, NPSTORET, has five digit parameter codes. The following table outlines the different types of flow parameters, and their associated codes included in NPSTORET.

Table 2. NPSTORET Flow Monitoring Codes and Definitions

| | |
|------------------------|---|
| Flow (00061) | Measurements reported in cubic feet per second. Report instantaneous flow as follows: <ul style="list-style-type: none">•Report values less than 10 but greater than 0.1 cfs to the nearest tenth (for example, 9.35 to 9.4).•Report values greater than 10 cfs to the nearest whole number (for example, 20.62 to 21).•Report actual values less than 0.1 cfs but greater than or equal to 0.01 cfs. These values should not be rounded (for example, 0.07 would be reported as 0.07).•Report flow values < 0.01 cfs as < 0.01. |
| Flow method (89835) | Refer to codes in NPSTORET |
| Flow, severity (01351) | When there is no flow (pools) report a flow severity of 1, and the instantaneous flow (00061) as 0.0 cfs. If the stream is dry, record only the flow severity value of 6. (1-No Flow, 2-Low Flow, 3-Normal, 4-Flood, 5-High, 6-Dry) |

Flow values should be reported in (ft³/s). The flow measurement method should be reported along with the flow value or estimate.

5.0 REFERENCES

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APPENDIX A

Field Form for Recording Flow Measurements

Station ID _____
 Site Location _____
 Date _____ Time _____ PST
 Field Crew _____
 Field Conditions _____

Begin Time:
End Time:
Gauge height:

Notes from USGS Flow Measurement Methods:

- For shallow depths, use 6/10 method
- For deep depths (> 1.5 ft) use the 2/10 and 8/10 method
 - To get 2/10 depth multiply 6/10 depth by 2
 - To get 8/10 depth divide 6/10 depth by 2
- Space the verticals so that no sub-section has more than 10% (ideally 5%) of the discharge
- There should be 20-30 sub-sections
- Keep the first sub-section as small as possible (depth will often be zero and assume no flow)
- Parts of the stream cross-sections with greater depth and velocity should have closer verticals
- Face the bank while taking measurement (stand beside not behind wading rod)
- Position yourself at least 18' from the wading rod
- Measure velocity for at least 40 seconds
- Check the meter during measurement
- Have an idea what the discharge will be before measurement
- Read gauge height after measurement
- Reach should be straight and uniform; measure downstream of riffle
- Streambed should be free of large rocks, obstructions

